Aquacultural Engineering 82 (2018) 46–55

Contents lists available at ScienceDirect

Aquacultural Engineering

journal homepage: www.elsevier.com/locate/aque

Enhancing water use efficiency in monoculture of *Litopenaeus vannamei*: Impacts on pond water quality, waste production, water footprint and production performance

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ARTICLE INFO

Keywords:
Litopenaeus vannamei
Water use efficiency
Water balance study
Water quality
Waste production
Water footprint

ABSTRACT

We studied the effect of rearing densities of Pacific white shrimp, *Litopenaeus vannamei* in three densities with three replicate treatments [T_1: 0.4 million post-larvae (PL) ha^{-1}, T_2: 0.5 million PL ha^{-1}, T_3: 0.6 million PL ha^{-1}] and water cutback approach on rearing environment, water use efficiency, water footprint and production performance. Conditional water exchange was carried out based on water quality parameters. Water quality suitability index was very good (7.5–9.0) up to 13th, 10th and 5th week of culture in T_1, T_2 and T_3, respectively; which was attributed to rearing density, smaller-sized shrimp and low early feed input. Optimum rearing density of 50 PL m^{-2} (T_2) led to total water use of 3.25×10^4 m^3. It was seeming as a way to improve shrimp productivity (10.58 t ha^{-1} 120 d^{-1}), consumptive water use index (1.72 $m^3 kg^{-1}$ biomass), total water footprint (1229 $m^3 t^{-1}$ biomass) and net consumptive water productivity (USD 1.28 m^{-3}). L. *vannamei* culture with low to moderate water exchange as in T_2, helped uphold water quality suitable for the shrimp growth, improved water use efficiency (0.58 kg biomass m^{-3} water), minimized sediment load (45.3 $m^3 t^{-1}$ biomass), effluent outputs (0.63×10^4 m^3), pumping cost (USD 30.1 t^{-1} biomass produced), and ratio of output value to the cost of cultivation (1.97). The findings and advancement in knowledge would offer the basis to augment shrimp rearing efforts and the water management approaches will help in preventing the production of waste and effluent while increasing water use efficiency and production performance.

1. Introduction

Shrimp aquaculture is a highly lucrative farm enterprise and livelihood option for a large number of farmers in coastal India and most Asian countries. Because of high monetary returns, shrimp farming plays an imperative role in economic progress of farmers. Globally, demand for shrimp is growing steadily, while the world shrimp fishery is diminishing or remaining stagnant; only aquaculture can meet this demand (Bondad-Reantaso et al., 2012). In India, shrimp farming was tantamount with the monoculture of black tiger shrimp, Penaeus monodon till 2009. During the previous few years, white spot disease (WSD) has caused severe impairment to shrimp culture industry, mainly in coastal India and other parts of Asia leading to huge financial losses. So the aquaculturists were utterly looking for an alternate species and slowly shifted to *Litopenaeus vannamei*, known as the Pacific white shrimp (FAO, 2012) due to the availability selectively bred Specific Pathogen Free (SPF) seeds.

Since introduction, farming area of L. *vannamei* has increased in India intensely from 283 to 50,241 ha during 2010–2016 (Kumaran et al., 2017) and the production has also increased from a mere 17.31×10^5 – 4060×10^5 kg during the same period (MPEDA, 2017). Having the potential of 1.2 million ha brackish water area, land coverage under L. *vannamei* is expanding rapidly due to its acceptance to a wide range of salinities (0 to 45 ppt), amenable for high density rearing, column feeding habit, higher meat (65–70%) content and low dietetic protein requirement (Kumaran et al., 2017). However, rapid expansion of high-density L. *vannamei* culture with high nutrient input and excess water exchange has not only created apprehension for coastal water pollution but also the interest of other users.

More often than not, shrimp farmers do unplanned water exchange that becomes counterproductive and uneconomical. Conventional shrimp ponds usually require daily water exchange at rate of approximately 10–15% of total volume to maintain ideal water quality (Krummenauer et al., 2016). However, this strategy contributes to increased effluent output and exacerbate water pumping expenses (De Schryver et al., 2008). Due to the disposal of organic and nutrient rich shrimp pond effluent, coastal environments also suffer from oxygen exhaustion, low transparency, fluctuations in benthic population

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https://doi.org/10.1016/j.aquaeng.2018.06.004
Received 1 February 2018; Received in revised form 6 April 2018; Accepted 11 June 2018
Available online 21 June 2018
0144-8609/

structure and eutrophication (Casillas-Hernández et al., 2007; Páez-Osuna, 2001). Waning water quality not only a foremost factor abating shrimp yield and water productivity (Ma et al., 2013; Mohanty et al., 2014a) but affects growth and survival of aquatic organisms. Thus, shrimp pond water budgeting and quality assessment, and monitoring play a significant role in crisis management that minimizes environmental damage.

Further, enhancing water productivity in shrimp culture is prerequisite and there has been the necessity to determine ideal quantity of water essential for successful culture operation (Krummenauer et al., 2016). In addition to water quality assessment and monitoring in coastal shrimp culture, aquaculture water management also aims at quantification and minimization of water use. The future expansion of shrimp culture requires responsible management to increase operational efficacy and help avert wasteful use of water, effluent release and environmental deterioration of coastal environments through water cutback approach. Water budgeting and density-specific water use are therefore, two major necessities in refining coastal grow-out shrimp culture practice (Mohanty et al., 2014a).

So far, no study has been described on density-specific water use in grow-out culture of L.*vannamei* and its effect on production performance, water productivity and water footprint. However, several studies have been conducted on the water quality requirement (Cohen et al., 2005; Ray et al., 2011; Ma et al., 2013; Brito et al., 2014; Yan et al., 2007), feeding management (Carvajal-Valdes et al., 2012; Patnaik and Samocha, 2009), growth (Bett and Vinatea, 2009; Sookying et al., 2011; Williams et al., 1996), and rearing density (Araneda et al., 2008; Moss and Moss, 2004; Schveitzer et al., 2013; Casillas-Hernández et al., 2007; Sookying and Davis, 2011) of this species,. Keeping in view the significance of water budgeting, we examined different aspects of hydrological water balance study to quantify water requirement and water use efficiency. This would help in minimizing wasteful use of water, production cost and enhancing the production performance, water productivity and water footprint in monoculture of L. *vannamei* with changing intensity levels.

2. Material and methods

2.1. Pre and post-stocking shrimp pond management

This field experiment using brackish water was conducted for monoculture of L. *vannamei* at Chandipur (21° 28′ 44″ N, 87° 02′ 15″ E), Odisha, India, during 2015-2017. Rearing density was taken as treatment [T_1: 0.4 million twenty-day-old post larvae (PL_{20}) ha^{-1}, T_2: 0.5 million PL_{20} ha^{-1}, T_3: 0.6 million PL_{20} ha^{-1}] in randomized block design. Each treatment with three replications were undertaken. Water surface area (WSA) of each earthen shrimp pond was 5000 m^2. In all the treatments, pond and inputs management practices were similar. Every year, only summer season crop of 120 days duration were undertaken (altogether three crops in three years). Prior to stocking, pond bottom preparation involved length-wise tilling followed by lime ($CaCO_3$) application (400 kg ha^{-1}) and after that width-wise cross ploughing followed by use of $CaCO_3$ at the rate of 200 kg ha^{-1}. After tilling and liming, dechlorinated water from the reservoir was allowed through pumping to fill each pond up to desired depth. Reservoir water was treated with bleaching powder (available chlorine - 26%) at the rate of 15 ppm followed by aeration using paddle wheel aerators for dechlorination. Combined application of fertilizer (4 ppm rate, urea: single super phosphate:: 1:1) was carried out after water filling which was equivalent to N:P of 6.6:1. Two weeks after water culture, post-larvae (PL_{20}) stocking was carried out in ponds with appropriate acclimatization practice (Mohanty, 1999). Intermittent fertilization (at the rate of 1.5–2.0 ppm) and liming (at the rate of 100-120 kg ha^{-1}) depending upon water quality was carried out to uphold plankton density in pond eco-system. Regular pond water aeration practice was 10-hours per day up to 50 days of culture (50-DOC), 14-hours per day during 51–90 DOC and 18-hours per day thereafter till harvesting (91–120 DOC). Night time aeration was continuous (12.30–5.30 AM) after 50 DOC. Four 2-hp paddle wheel aerators were used in each pond. Depending on water quality variation, conditional pond water exchange (WE) was carried out. The amount of WE was decided on the basis of kg. shrimp m^{-2} × (100 × EF), where EF = exchange factor i.e., 0.15-0.25 for stocking density of 40-60 PL_{20-22} m^{-2}.WE was only permissible when (1) deviation in average water pH in a day was more than 1.0 or (2) dissolved oxygen dropped below 3.0 ppm or (3) water quality suitability index (WQSI) was close to 5.5. WQSI that expresses the overall water quality in a given place and time based on different hydro-biochemical variables were calculated (Mohanty et al., 2017).

2.2. Water quality assessment, monitoring and budgeting

Initial water depth of 120 cm was maintained in each pond up to 30-DOC and increased to 150 cm thereafter till harvesting (31–120 DOC). Required pond water depth was upheld on weekly basis either adding or removing water. Water pH, temperature, dissolved oxygen (DO) and transparency were monitored twice a day (morning and afternoon) using Multi-parameter Water Analyzer (YK-611, Yeo-Kal Electronics Pty. Ltd., Australia). DO was also monitored in the night (12.30–1.00 AM) in addition to morning and afternoon measurements after check-tray monitoring of last meal. Pond water salinity was measured daily using refractometer (ATAGO S-10, Japan). Weekly monitoring of total suspended solids (TSS, Gravimetric, after evaporation and ignition at 103 °C), dissolved organic matter (DOM, Walkley and Black Method), CO_2 and total alkalinity (titrimetric method) were carried out (APHA, 1995; Biswas, 1993). Acetone extraction method (Strickland and Parsons, 1972) was followed for estimation of chlorophyll-*a* while, spectrophotometer was used for determination of NH_4^+ using the indophenol blue method (Biswas, 1993). Primary productivity (oxygen method), nitrate (phenol disulphonic acid method), nitrite (azoditization colorimetric method) and phosphate (ascorbic acid method) analysis were carried out (APHA, 1995; Biswas, 1993). Fortnightly collection of plankton samples, its preservation and estimation (qualitative and quantitative) was carried out as described by Dash and Pattanaik (1994).

To evaluate the classes of suitability (Table 1) of pond water quality for shrimp culture, WQSI (water quality suitability index) was estimated as described by Mohanty et al. (2017). Hydrological water balance study was carried out as described by Mohanty et al. (2014b) and

Table 1
Range and classes of water quality suitability index (WQSI) for *Litopenaeus vannamei* culture.

Weight range	Salinity (PSU)	Turbidity (NTU)	pH	DO (ppm)	WQSI range and classes of water quality suitability (Source: Beltrame et al., 2006)
5	30	< 10	8.0	> 7.0	• > 9.0 - Suitable (excellent quality), needs no management
4-5	20-30 or 30-35	10-20	7.5-8.0 or 8.0-8.5	6.0-7.0	• 7.5 to 9.0 - Suitable (very good), needs little management
3-4	15-20 or 35-40	20-35	7.0-7.5 or 8.5-9.0	5.0-6.0	• 5.5 to 7.5 - Suitable (good), needs moderate management
2-3	10-15 or 40-45	35-60	6.5-7.0 or 9.0-9.5	4.0-5.0	• 3.0 to 5.5 - Acceptable, needs intensified management
1-2	5-10 or 45-50	60-100	6.0-6.5 or 9.5-10	3.0-4.0	• < 3.0 - Unsuitable
0-1	0-5	100-150	5.5-6.0 or 10-10.5	2.0-3.0	
Variable weight	***5***	***3***	***2***	***1***	